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Review

Properties of cement-based composites using nanoparticles: A comprehensive review

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HIGHLIGHTS

- Influence of nanoparticles on the properties of cement-based materials is discussed.
- Nanoparticles can significantly alter the hydration mechanism of cement paste.
- Research needs are identified based on the gaps in the current state of knowledge.

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ABSTRACT

This review paper intends to synthesise the data published in the literature on the uses of different types of nanomaterials in cementitious materials. According to ASTM, depending on types, the size of nanoparticles varies from 1 nm to 100 nm. Application of nanomaterials in different sectors has shown that the properties of conventional materials can be significantly improved when nanoparticles are included. The addition of nanoparticles in cementitious materials can act as a filler agent, producing a dense matrix and reduce the growth of micro pores. Some nanoparticles also help in the secondary reactions forming cement composite and contribute to the strength development. Moreover, this paper summarises the current knowledge of the microstructure, mechanical strength and durability of cementitious materials when incorporating different types of nanoparticles. In addition, research needs are identified based on the gaps in the current state of knowledge on using nanoparticles in cement-based construction materials.

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1. Introduction

Modern technologies as well as phenomena in nature have opened up new windows for researchers to emerging and interdisciplinary fields of study, including nanotechnology [1,2]. As science advances, these fields are becoming more specialised, leading to entirely new avenues of inquiry. At the same time, the competitiveness of new technologies and materials is also growing rapidly [3–7]. Some come and go, whereas others develop into new, well-recognised entities. In the last few decades, nanotechnology has grown in various sectors such as energy, chemistry, agriculture, aerospace, healthcare, construction, electrical, etc. [8–11]. Concrete is an affordable and widely available construction material and second only to water consumption per capita. However, as the main ingredient of concrete, cement is not environmental friendly, as production of 1 ton cement emits on average 0.7 ton of CO_2 to the atmosphere [12,13]. Therefore, it is necessary to review concrete ingredients and include more environmental friendly products such as industrial by products, recycled materials, and waste streams. Alternative binder materials such as fly ash, slag and silica fume are used to replace cement partially in concrete [14,15]. In addition to benefits to the cement-based composite, the use of these waste stream materials reduces the overall impact on the environment and its sustainability.

Nanotechnology is being adopted to improve the performance of existing materials like concrete. However, the main debate is whether nanomaterials can show similar performance in concrete compared to areas such as the biomedical and electronic industries where nanomaterials are successfully adopted and have shown great improvement over conventional materials [4,5]. Research focussed on nano-concrete has therefore concentrated on suitability of different types of nanoparticles to enhance different features of concretes, their optimum dosages, cost, etc. The main characteristic of nanoparticles is that they have high surface-area-to volume ratio [15]. Therefore, more atoms can be expected on the surface of nanoparticles rendering them highly reactive [16]. The behaviour of such materials is mainly influenced by chemical reactions at the interface. Also, these nanoparticles can easily form agglomerates if not properly distributed in to the mix. Higher surface area of the particles in cementitious composite require more water to be wetted, resulting in less free dispersant water available in the mixture in aqueous systems [15]. Therefore, the use of nanoparticles in cementitious composites can significantly modify the behaviour not only in the fresh, but also in the hardened conditions, as

Table 1
Different types of nanoparticles in concrete and their different properties reported in this review.

Nanomaterial	SiO_2	TiO_2	ZrO_2	Al_2O_3	Fe_2O_3	Nano fly ash	Graphene Oxide	CNF	CNT	Nano clay	Zeolite	
											Natural	PWC
1. Rheology (Section 3)												
Slump reduction	√	√		√	√						√	
Pressure on formwork										√		
Green strength increased												
Reduced setting time	√	√								√		
Viscosity and yield stress increased	√									√		
2. Heat of Hydration (Section 2.2)	√	√		√					√			
3. Mechanical (Section 4)	√	√	√	√	√	√	√	√	√	√	√	√
4. Microstructure (Section 5)	√						√	√	√		√	√
5. Shrinkage (Section 6)												
Drying shrinkage											√	√
Autogeneous shrinkage									√			
6. Durability (Section 7)												
Water absorption		√	√	√	√						√	√
Oxygen permeability												√
Chloride ingress		√									√	√
Corrosion rate									√		√	√